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ABSTRACT

This study assessed the effectiveness of integrating logical thinking skills into a geology course designed for nonscience majors. Goals of the study were to: (1) design a unique set of materials that integrated logical skills and geological time and sequence; (2) implement these materials into the classroom instruction; and (3) test the effects on both geological achievement and critical thinking. Results show that a treatment group experienced significantly greater change than a control group in both critical thinking and geological achievement, demonstrating that college students can learn the complex rules of logical reasoning if those rules are presented in a manner understandable to them. In addition, the study demonstrates that college students are capable of applying these rules successfully in a setting such as geology. Although the full long-range impact of teaching logic as a reasoning tool has not yet been determined, the powerful implications such a tool has in increasing an individual's ability to think more critically and rationally are only beginning to manifest themselves in a wide range of possibilities. Future efforts need to focus on determining if this method can be successfully used in other sciences or with younger students. (JN)

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The Effects of Teaching Logical Reasoning Upon Students' Critical Thinking and Science Achievement

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The Effects of Teaching Logical Reasoning Upon Students' Critical Thinking and Science Achievement

The development of scientifically literate and concerned individuals with a high competence for rational thought and action has long been one of the goals of science education (NSTA,1971). Science by its very nature is a logical discipline that requires certain rational thinking skills to solve problems. In recent years, the amount of scientific information has increased in complexity as well as volume and these same thinking skills are now becoming essential to everyone in order to make sense of all this information, as well as the world around them.

During the latter part of the twentieth century, the rapid pace of the developments in science and technology has led to a sharp increase in the volume of knowledge needed by the individual of today (Purcell, 1977). New industries have arisen in the fields of computer science, data processing, aerospace, petrochemicals and scores of others that demand that individuals learn to cope more effectively with the complexities of modern life. New information is now reaching people at faster and faster rates, and individuals are continuously in need of replacing old images and ideas of the way things used to be with new images and understandings of what is now taking place all around them. Thus this need requires a more logical, rational and innovative method of reasoning, interpreting and integrating ideas than has ever before been demanded.

According to Lamm (1976) individuals are best able to function in today's complex scientific world when they can utilize their thought processes effectively in order to analyze, interpret and critically

accept only those opinions, elements of knowledge and information which have been proven to be valid and reliable. Only a minority of individuals, however, have been able to meet such standards. Allen (1975) in his work with junior high school students, found that through voice intonation and rapid hand movements, he was able to make his students believe and accept unfounded conclusions, one being that a pencil could be broken by a strand of hair. His students perceived the accomplishment of the feat take place and accepted that it could be done. This experiment enabled Allen to observe the relative ease with which individuals can be led into accepting ideas presented to them. Even many of today's college students have found themselves overwhelmed by and often failing courses that require them to reason critically, objectively, and logically (Arons, 1977).

The Commission on the Humanities, sponsored by the Rockefeller Foundation, reported that explicit principles for reasoning, namely, critical thinking, should have an important place in the American educational system. The Commission stated: "the Department of Education should define critical thinking as one of the basic skills that provides the foundation for advanced skills of all kinds" (Commission on the Humanities, 1980).

Ennis (1969), however, has stated that there is a difference between critical and rational thinking. Ennis (1962) defined critical thinking as the "correct assessment of statements" and has said that while it is an important attribute of the individual's intellectual capabilities to be able to think critically, critical thinking alone is not sufficient. Critical thinking should be recognized as an important foundation of an individual's reasoning process, but it should have as its goal the actualization of rational thought.

Ennis (1969) defined rational thinkers as individuals who are proficient at observing, inferring an explanation, generalizing, conceiving and stating assumptions, alternatives, plans and predictions, offering a well-organized and well-formulated line of reasoning, evaluating authoritative, sounding statements and definitions. Rational thinkers may also be said to have the tendency to take into account the total situation, be well-informed, demand as much precision as the subject matter permits, deal with the parts of a complex situation in an orderly fashion, consider seriously other points of view than one's own, withhold judgement when the evidence and/or reasons are insufficient, take a position, and change the position when the evidence and reasons are sufficient to warrant doing so and accept the necessity of exercising infermed judgement (Ennis, 1969). The importance of rational thinking in science can easily be seen by examining the skills and processes that are usually encorporated in the scientific method. These skills, such as defining a problem, assessing the evidence, determining relationships and posing solutions, are not only the skills used in rational thinking but also the very same skills that provide the information for scientific investigations. The recent science curricula all have been based on the enhancement of these same skills (Shymansky, etal, 1983)

Logic, a branch of philosophy, is a reasoning tool with broad applicability. The critical standards of logic have application in any subject which employs inference and argument, in any field in which conclusions are supported by evidence. This includes every domain of serious intellectual endeavor as well as practical affairs of everyday life (Salmon, 1963). According to Harris (1977) logicians "have long been fond of pointing out that the rules of logic are basic

to all knowledge, to all reasoning processes, to all discipline of study." Lipman (1980) has stated that the teaching of logic to students can benefit them by helping them to think rationally and critically. The principle rules of logic will provide students with criteria against which they will be better able to judge situations, statements, information they receive more critically and learn to make rational inferences and valid conclusions from them.

The use of logic as a tool to improve reasoning skills in college students is not a new idea, but to incorporate successfully the teaching of logic directly into existing course content is an idea that is receiving consideration (Haws, 1983). Because of the vast technological advances being made today and the new knowledge being learned, it would be reasonable to provide students on all levels of formal education with the methodology and logical rules that allow individuals to deal with new data systemically, consistently and orderly. Logical thinking requires the ability to make valid inferences that a person can indicate by explicit inference to specific rules of inferences. The students must learn to avoid formal fallacies in reasoning, and this cannot be done by trial and error. The person who is least able to abstract and generalize on his/her own is the underperformer.

Logic would seem to be a natural part of science. The scientific method draws on the skills of logic heavily by relying on deductive and inductive reasoning. Geology being a part of science shares this natural tendency to encorporate logic into its method of solving problems. Courses in logic are not viable solutions since the curriculum is already over crowded. Also often these course in pure logic are too involved in the foreign language of logic and do provide

students with realistic applications. Geology and all sciences can provide a natural setting where these logical approaches can be used. In fact, geology demands such a approach because of its emphasis on basic assumptions and using these assumptions to explain what has occurred on the surface of the earth.

STATEMENT OF THE PROBLEM

In a rapidly changing society and scientific society, it is essential for individuals to think rationally and critically. The educational environment is the logical place to foster the development of rational and critical thought in science and particularly geology. Currently the educational system does not provide a specific program in geology designed to assist student growth in rational and critical thought. In order to develop such a program, a determination must first be made of the appropriate intellectual tool, namely logic, to be integrated directly into a course of geological study. Further a determination must also be made of the appropriate methodologies/strategies needed to assist teachers in actualizing this growth in their students.

PURPOSE OF THE STUDY

This study explores the development of a geological course based on rational and critical thinking. The course encorporated logic into a geology course designed for nonscience majors. This study assessed its usefulness in not only increasing achievement in geology but also in increasing critical thinking.

RESEARCH QUESTIONS

The following questions are asked:

1. Do students in the treatment group score significantly different from students in the control group on a geological achievement test

and on the Watson-Glaser Thinking Appraisal Instrument ?

2. Do male and female students in the treatment group score significantly different from students in the control group on a geological achievement test and on the Watson-Glaser Critical Thinking Appraisal Instrument ?

3. Is the effect of gender constant across groups?

DEVELOPMENT OF MATERIALS

The problem, then, was to produce geological materials that enhance rational and critical thinking through the integration of logic. From a search of available materials, it was apparent that no such materials existed. Thus, to create these materials, our attention was focused on one topical area of geology that seemed appropriate. The area identified was: time and sequence. This topic is usually included in most geology courses, and seemed to be an obvious area where logic could be integrated.

Examining this area, we began to identify logical principles that could be helpful to students in understanding the concepts and procedures of geologic time and sequence. The following areas of logic were identified: observation, deduction, induction, possibility/probability, and cause/effect. After identifying these areas, we also searched for existing materials that focused on these logical principles. These materials were primarily used to teach pure logic. Many of them were too lengthy and symbolically based. However, they did serve as a good starting point.

The materials produced by the authors were based on both logic and geology. Each logical principle was first approached by using common everyday examples. After practicing with these examples, the student would then be introduced to geological examples that relied on

the same logical principles. Symbolic logic was totally avoided in all activities since students are usually confused by this. Geological activities were produced that integrated all of the previously mentioned logical principles. They included both hands-on activities and group discussion activities. These activities were sequenced in such a manner not only to build the geological ideas concerning time and sequence but also to build the logical principles now integrated into geological subject matter. A sample of some of the materials have been included in the appendix. However, as an illustration, let us look specifically at the activities concerning observations and inferences (see appendix). To introduce observing and inferring, a hands-on activity involving glass rods was used to familarize the students with the problem of forming careful observations and then attempting to explain these observations with an inference. The students are instructed to view through a glass rod a series of words which are different colors. This activity creates somewhat of a discrepant event because to the careless observer it appears as if only the words that are a certain color are affected by the glass rod. Next, to further demonstrate the skills of observing and inferring, a series of events are presented to the students. The student is to react to each of these situations and then be able to discuss them with the rest of the class. These discussion situations ranged from common everyday occurrences to ones with a geological flavor.

PROCEDURES OF THE STUDY

Community college students enrolled in a nonscience major geology course were the subjects of this study. The subjects were divided into two intact groups. One group was designated as the control group

and received no instruction in logic. The treatment group received instruction in logic through the use of both geological and non-geological activities. These activities were developed by the investigators and both classes were taught by one of the investigators. The time of treatment was one month and instruction centered on geological time and sequence. Subjects in both groups were given the following instruments:

1. Biographical Questionnaire: This questionnaire assessed the subjects science background and determine certain demographic data. It was given at the beginning of the semester.

2. Watson-Glaser Critical Thinking Appraisal - Form A of this instrument was given as the pretest and form B was given as the posttest. Both forms consist of 80 items and are appropriate for the ninth grade through adult levels. The appraisal is divided into five subtests. The maximum score on both forms is 80, and this score is obtained by totaling the number of correct responses. The reliability of the Watson-Glaser Critical Thinking Appraisal (WG) was determined in a variety of ways. Split-half and alternative forms of reliability coefficients ranged from .69 to .85 (Watson & Glaser,1980). Validity was assessed by examining situations that focused on both content and construct validity. In all instances, the WG has proved to be a valid measure of the trait called critical thinking. The symbol, WG, was used for this instrument.

3. Geological Achievement Test: This test developed by the investigators was used as measure of achievement. Its reliability was determined by the coefficient alpha which evaluates the internal consistency of the items on the instrument. The coefficient was .78. The form of the test was multiple choice. It consisted of 44

questions. The symbol, ACH, was used for this instrument.

RESULTS

This study was conducted to assess the effectiveness of integrating logical skills into a geology course designed for nonscience majors. The goals of this investigation were:

1. to design a unique set of materials that integrated logical skills and geological time and sequence;

2. to implement these materials into the classroom instruction;

3. to test the effects on both geological achievement and critical thinking.

To determine whether these goals were fulfilled, the data was analyzed using a multivariate analysis of covariance. However, first using the biographical questionnaire, a profile of the participants was determined. Eighty percent of the subjects were under the age of 20 with the average age being 27. This older type of student is expected in a community college setting since many are often returning to school after spending some time in the work force. None of the subjects were science majors and most listed business as their field of study. The subjects had completed an average of 30 college hours with an approximate grade point average of 3.0 (B). Ninety-nine percent had no or only one college science course. When asked why they took this particular course, most answered that it seemed less threatening because it was designed for nonscience majors.

Descriptive statistics for the covariate (WG pretest) for each group are presented in Table 1. Because the covariate was related to the dependent variables, its primary function in the analysis was the identification of a systematic source of variance. Since there may have been some initial differences among the subjects on the

covariate, the process of removing its effect from the dependent variables was performed. With the removal of the covariate effects from the dependent variables, an adjustment in the means of the dependent variables occurred to account for these initial differences. Table 2 shows the adjusted means for the WG (posttest) and ACH. The adjustments, then, were the values upon which the assessment concerning possible significant differences was made.

Tests of Hypotheses

Using the Statistical Package for the Social Sciences (Nie, 1984), the testing of the hypotheses involved was done. Table 3 presents a summary of the findings.

Group

Question 1: Do students in the treatment group score significantly different from students in the control group on a geological achievement test and on the Watson-Glaser Critical Thinking Appraisal Instrument? The calculated test statistic, $F(2,44) = 25.48$, $p < .05$, exceeded the critical value.

The combined dependent variables were significantly related to the independent variable, group.

Gender

Question 2: Do male and female students in the treatment group score significantly different from students in the control group on a geological achievement test and on the Watson-Glaser Critical Thinking Appraisal Instrument? The calculated test statistic, $F(2,44) = 1.41$, $p > .05$, did not exceed the critical value for F. The combined dependent variables were not significantly related to gender of students.

Interaction

Question 3: Is the effect of gender constant across groups? The calculated test statistic, $F(2,44) = 2.76$, $p > .05$, did not exceed the critical value for F. The effects of gender was statistically the same across all groups.

Strength of Association

Since there was a difference between the two groups, it was concluded, at least, that some association existed between the independent variable, group, and the linear combination of dependent variable scores. An assessment of the strength of this association was made in order to determine how much association there was, i.e., the proportion of variance in the dependent variable scores that was attributable to differences among treatment.

Wilks Lambda was used to assess this strength. Since Wilks Lambda (Λ) was a ratio between the determinant of the error cross-product matrix and the determinant of the group effect plus error cross product matrices, it represented the proportion of variance that was not accounted for in the combination of dependent variables. Thus, $1 - \Lambda$ represented the proportion that was accounted for.

To assess the strength of association between the independent variable, group, and the combination of dependent variables, the following equation was used:

$$\eta^2 = 1 - \Lambda_{group} = 1 - .46339 = .53661$$

(Pedhauzur, 1982)

The equation indicated that 54% of the variance contained in the

combination of dependent variables (scores on WG posttest and ACH) was accounted by differences in group assignment. Taking the square root, we get η = .7. That is, the correlation between scores on the dependent variables and group assignment was .7. This represents a high correlation (Tabachnick, et al. 1983).

Post Hoc Analysis

A univariate analysis of covariance was conducted on each dependent variable separately with the effect of the covariate removed. The univariate F tests were calculated primarily as an aid in assessing which dependent variable might be contributing to the significant multivariate F. The ANCOVA summary table described in Table 4 reflects that both dependent variables were responsible for the significant differences concerning group differences. The probability level associated with both the multivariate F test and the univariate F tests (with no adjustment made for the alpha level) has indicated that both dependent variables were responsible for contributing to the significant differences among the groups.

DISCUSSION AND IMPLICATIONS

The findings in this study have suggested some very interesting conclusions, namely, that individuals who are taught specific rules of thinking through the use of logic can achieve not only a significantly greater change in their critical thinking ability but also a significantly greater change in their achievement in geology.

One of the major goals of this study was to integrate the reasoning tool of logic into the existing geological college course curriculum. The treatment group, which was given this combined methodology, experienced significantly greater change than the control group in both critical thinking and geological achievement. Logic, as

a reasoning tool, however, has implications beyond assisting individuals in achieving higher in geology. Past research has shown the value of logic in assisting the decision making and reasoning skills of individuals in various activities of their daily lives (Haws, 1984). Therefore, as an extension of this study, logic may be considered as a useful tool to be taught (not as a separate course but integrated into existing course content) at all levels of the academic spectrum. Thus, students, in a mathematics or social science course, for example, might be taught specific rules or principles of reasoning to help them evaluate statements, opinions or ideas of others. Such a task would required the actual teaching of logical reasoning along with an existing course. This requirement would necessitate the training of teachers not only to learn rules of logical reasoning themselves but also to learn to integrate those rules successfully into their own courses.

For science these results point toward the importance of integrating logic into existing science curricula. The method employed by this study did not use an excessive amount of class time. The materials produced were easy to use, and they did accomplish the study's original goals. Science has a tendency to be taught as an unorganized collection of facts. Reasoning skills may provide a structure that could be used to provide science a more systematic and meaningful approach.

Because modern society is rapidly growing more complex in its technological achievements and the skills it requires of its members to cope with these achievements, the educational establishment has a profound obligation to people to prepare them for a future that promises to increase in its complexity and diversity. From this

study, teaching integrated logical reasoning at the collegiate level has been shown to be a meaningful instructional experience in developing an efficient means for individuals to begin to evaluate the ideas and statements of geology and other sciences more effectively.

This study demonstrated that college students can learn the complex rules of logical reasoning if those rules are presented in a manner understandable to them. Further, this study demonstrated that college students are capable of applying these rules successfully in a different setting such as geology. The full long-range impact of teaching logic as a reasoning tool, however, has not yet been determined. But the powerful implications such a tool has in increasing an individual's ability to think more critically and rationally are only beginning to manifest themselves in a wide range of possibilities.

This study also indicates other areas that should be investigated. Future efforts need to focus on determining if this method can be successfully used in other sciences and if this approach can be used with younger students.

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Table 1

Descriptive Statistics for Covariate Measure

For Group, Gender

	Treatment Group	Control Group	Overall Mean
Female			
WG (Pretest)	53.43 (8.60)*	50.71 (9.16)	52.07
Male			
WG (Pretest)	56.33 (12.85)	56.07 (9.68)	56.20
Overall Mean			
WG (Pretest)	54.88	53.39	

*First entry is cell mean; second entry is standard deviation.

Table 2

Adjusted Means on Dependent Variables

For Group, Gender

	Treatment Group	Control Group	Overall Mean
Female			
WG (Posttest)	58.95	51.70	55.32
ACH	37.08	29.56	33.32
Male			
WG (Posttest)	61.90	51.60	56.75
ACH	35.96	33.57	34.76
Overall Mean			
WG (Posttest)	60.42	51.65	
ACH	36.52	31.56	

Table 3

Multivariate Summary Table

Source of Variation	df	Λ	F	P
Group	2,44	.46	25.48	.000
Gender	2,44	.94	1.41	.255
Group X Gender	2,44	.89	2.76	.075

Table 4

Univariate Analyses

Dependent Variable: WG Post

Source of Variation	SS	df	MS	F	P
Adjusted Group Effect	883.09	1	883.09	28.24	.000
Res_{within}	1406.96	45	31.27		
Res_{total}	2290.05	46			

Dependent Variable: ACH Post

Source of Variation	SS	df	MS	F	P
Adjusted Group Effect	327.66	1	327.66	20.57	.000
Res_{within}	716.79	45	15.93		
Res_{total}	1044.45	46			

Acknowledgement

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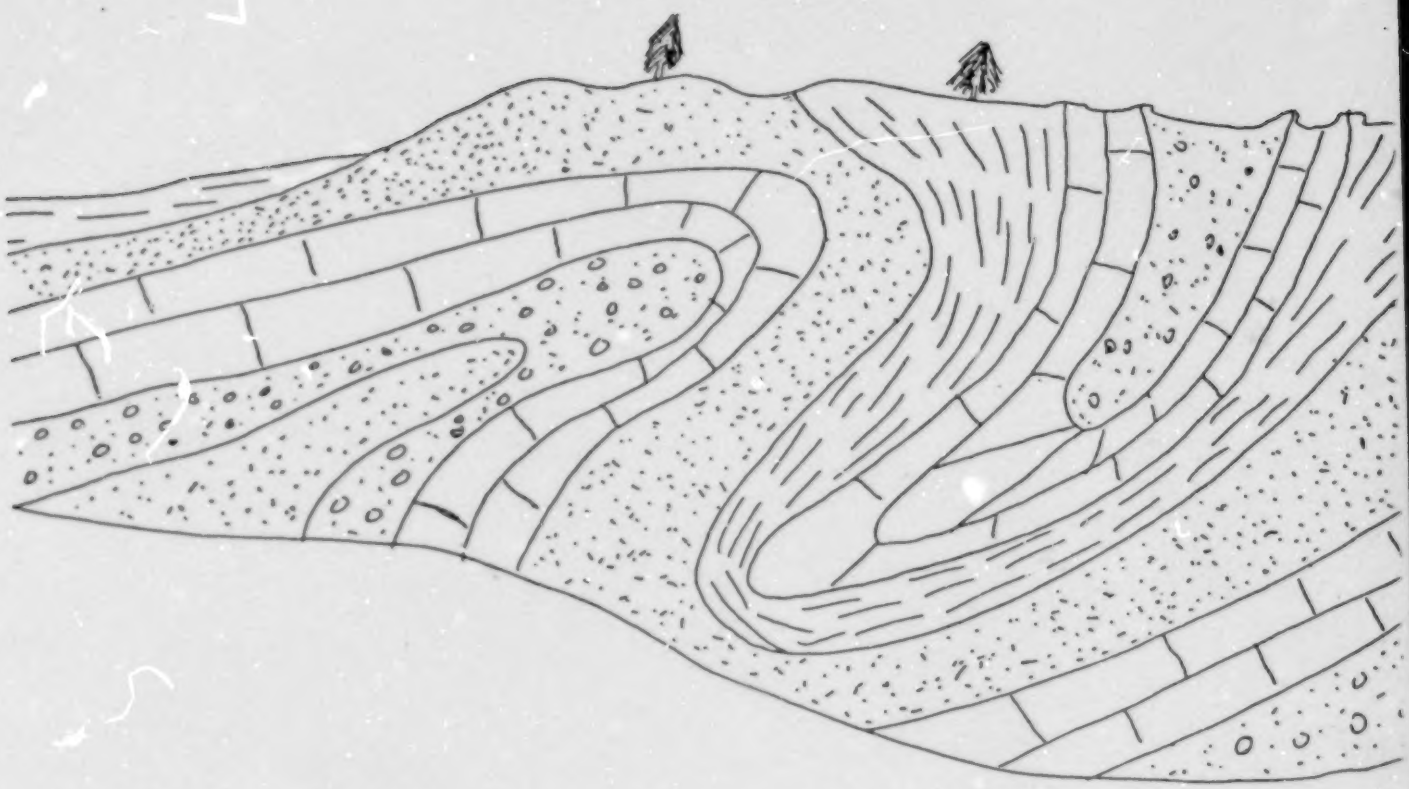
Appendix

GEOLOGIC TIME AND SEQUENCE

OR

WHAT HAPPENED WHEN?



GLASS RODS ACTIVITY
Observing and Inferring

Instructions:

Divide into groups of four. Each group will need a glass rod, a data sheet, a
a paper with different colored words. Place the rod directly on op of the words
on the paper and make some observations, then raise the glass rod about 1 cm and
observe what happens to the letters. Write your observations in the space provided

Observations:

Self-Check: Are all your observations acquired through the use of your five senses?

Construct some inferences to explain your observations? Write them below.

Self-Check: Are your inferences based upon your observations written above?

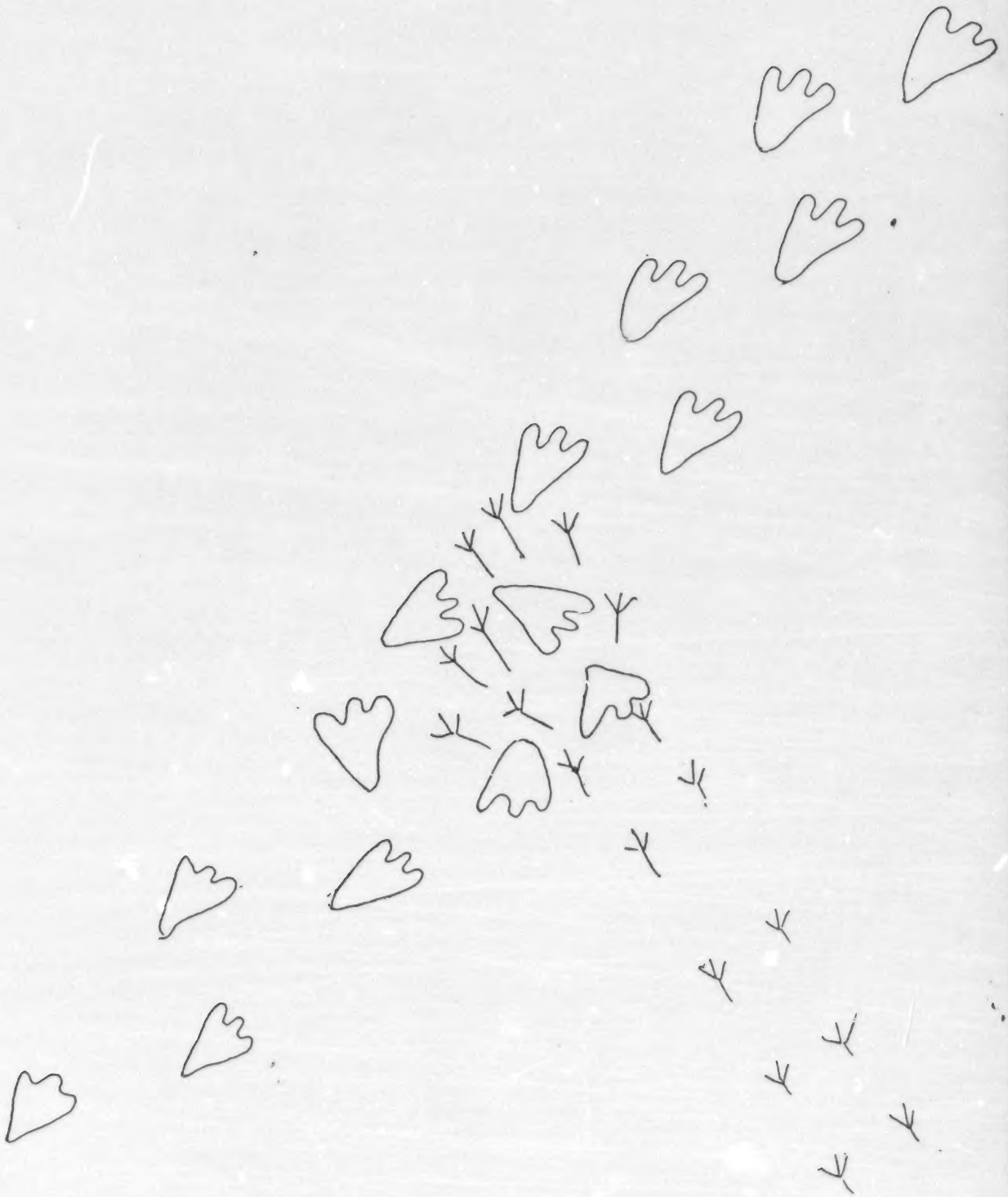
Test some of these inferences while in your groups. Write results of testing on your data sheets. Regroup and be prepared to discuss your results.

TRACKS

Look at the following page that contains tracks that were found preserved in limestone in Glen Rose, Texas. What observations could you make about them? Write your observations below.

Based upon your observations, what could explain these patterns? Write your inferences below.

Be prepared to discuss your observations and inferences.



Inferring

To solve a problem, scientists logically collect data by using their five senses. This data is then analyzed and inferences are proposed based on the observations. Inferences are the results of patterns that may be ascertained through a careful examination of observations. These inferences may lead to generalizations or laws that may be used in similar situations.

When something is inferred, there is a judgement that is made. For it to be a valid inference, these judgements need to be true.

Look at the following examples of inferences. Are they valid judgements? Be prepared to discuss your decisions.

Situation 1: Bill Said, "Hi, John!" John smiled and said hello. Bill inferred that John was friendly. Is this a valid judgement? Write your decisions below

Situation 2: Mary read the headline,

"Cat" Burgular Caught

Mary inferred that a cat who had been stealing had been caught. Was this a valid judgement? Write your decision below.

Situation 3: John saw a sign at the beach.

SHARKS
NO SWIMMING

He inferred that sharks were not allowed to swim there.

Was this a valid judgment? Write your decision below.

Situation 4: New places with crude oil deposits are hard to find. There is an area where no crude oil has been found before but which looks promising. About seven out of every eight wells drilled are dry - that is, they produce no oil. It costs anywhere from $90,000 to $2,000,000 to drill an oil well.

Mr Smith knows a geologist who says she has found a place which looks like it might have crude oil. The geologist is trying to find people willing to invest money to drill for oil there. Mr. Smith has $3,000 to invest, but he can't afford to los it. On the other hand, he knows he could get rich if the oil well strikes oil.

Should Mr. Smith invest the money or not?

Why? or why not?

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